

Strong two-body decays of the $\Lambda_c(2940)^+$ in a hadronic molecule picture

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The $\Lambda_c(2940)^+$ baryon with possible quantum numbers $J^P = \frac{1}{2}^+$ and $\frac{1}{2}^-$ is studied as a molecular state composed of a nucleon and D^* meson. We give predictions for the strong two-body decay channels $\Lambda_c(2940)^+ \rightarrow pD^0$, $\Sigma_c^{++}\pi^-$ and $\Sigma_c^0\pi^+$ where the sum of partial widths is consistent with current data for the case of $J^P = \frac{1}{2}^+$. The case of $J^P = \frac{1}{2}^-$ is shown to be ruled out.

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I. INTRODUCTION

Recently a new baryon resonance $\Lambda_c(2940)^+$ has been discovered in the decay channel $D^0 p$ by the *BABAR* Collaboration [1] and confirmed as a resonant structure in the final state $\Sigma_c(2455)^{0,++}\pi^\pm \rightarrow \Lambda_c^+\pi^+\pi^-$ by Belle [2]. Both collaborations report on values for the mass and width of the $\Lambda_c(2940)^+$ state which are consistent with each other: $m_{\Lambda_c} = 2939.8 \pm 1.3 \pm 1.0$ MeV and $\Gamma_{\Lambda_c} = 17.5 \pm 5.2 \pm 5.9$ MeV (*BABAR* [1]); $m_{\Lambda_c} = 2938.0 \pm 1.3_{-4.0}^{+2.0}$ MeV and $\Gamma_{\Lambda_c} = 13_{-5}^{+8} {}_{-7}^{+27}$ MeV (Belle [2]).

In Ref. [3] it was proposed that $\Lambda_c(2940)^+$ could be a $D^{*0}p$ molecular state with spin-parity $J^P = \frac{1}{2}^-$ or $\frac{3}{2}^-$, essentially because its mass is just a few MeV below the $D^{*0}p$ threshold value. There it was also shown that the meson-exchange mechanism, such as π , ω and ρ exchange, can lead to binding in such a $D^{*0}p$ configuration. In contrast, according to the predictions of the relativized quark model the baryon state in the 2940 MeV mass region could have $J^P = \frac{3}{2}^+$ or $\frac{5}{2}^-$ [4]. A study of the decays in the 3P_0 model [5] excluded the possibility for $\Lambda_c(2940)^+$ to be the first radial excitation of the $\Lambda_c(2286)^+$ because the decay $\Lambda_c(2940)^+ \rightarrow D^0 p$ vanishes in this case. The possibility however that $\Lambda_c(2940)^+$ is a D -wave charmed baryon with $J^P = \frac{1}{2}^+$ or $\frac{3}{2}^+$ was shown to be favored. In a relativistic heavy quark-light diquark model [6] it is suggested that the $\Lambda_c(2940)^+$ state could be the first radial $2S$ excitation of the $\Sigma_c(2455)^+$ with $J^P = \frac{3}{2}^+$. It was also argued that the $\Lambda_c(2940)^+$ can result from the first orbital excitation of the light diquark in the $\Lambda_c(2286)^+$. An analysis of the strong decays of the $\Lambda_c(2940)^+$ in a chiral quark model [7] predicts that the $\Lambda_c(2940)^+$ is a D -wave state with principal quantum number $n = 2$. In Ref. [8] the strong decays of charmed baryons have been studied in the framework of heavy hadron chiral perturbation theory (HHChPT). The conclusion of [8] on the nature of the $\Lambda_c(2940)^+$ was that an experimental determination of the decay ratio $\Sigma_c^*\pi/\Sigma_c\pi$ will enable to discriminate the J^P assignments. In Ref. [9] the $\Lambda_c(2940)^+$ state with $J^P = \frac{1}{2}^-$ has been considered in the relativistic quark model. In Ref. [10] possible assignments ($J^P = \frac{1}{2}^+$, $\frac{3}{2}^+$ and $\frac{5}{2}^-$) for the $\Lambda_c(2940)^+$ states have been analyzed in the quark model. The predicted masses for the $\Lambda_c(2940)^+$ state are distributed in the range from 2.887 GeV to 2.983 GeV. The coupled-channel approach [11] does not generate any resonance in the energy region around 2940 MeV, which couples predominantly to the ND^* pair having its threshold only a few MeV above the $\Lambda_c(2940)$ mass. Therefore, the conclusion of Ref. [11] is that the $\Lambda_c(2940)$ is not a molecular ND^* system. Presently various possible structure interpretations exist for the $\Lambda_c(2940)^+$ baryon, also depending on the particular model applied (see e.g. Refs. [12–14]).

In this paper we consider the $\Lambda_c(2940)^+$ as a molecular state composed of a nucleon and a D^* meson. We also test the two currently possible assignments for the spin-parity quantum numbers of $J^P = \frac{1}{2}^+$ and $\frac{1}{2}^-$ in a molecular interpretation. Proceeding with this interpretation the strong two-body decay modes pD^0 , $\Sigma_c^{++}\pi^-$ and $\Sigma_c^0\pi^+$ of the $\Lambda_c(2940)^+$ are evaluated. As one result we deduce that the assignment of $J^P = \frac{1}{2}^+$ is favored in the molecular interpretation, while the case $J^P = \frac{1}{2}^-$ gives an overestimate for the total decay width. The technique for describing and treating composite hadron systems we developed already in Refs. [15, 16]. There we present the formalism for the study of recently observed unusual meson states (like $D_{s0}^*(2317)$, $D_{s1}(2460)$, $X(3872)$, $Y(3940)$, $Y(4140)$, ...) as hadronic molecules. The composite structure of these possible molecular states is set up by the compositeness condition $Z = 0$ [17–19] (see also Refs. [15, 16]). This condition implies that the renormalization constant of the hadron wave function is set equal to zero or that the hadron exists as a bound state of its constituents. The compositeness condition was originally applied to the study of the deuteron as a bound state of proton and neutron [17]. Then it was extensively used in low-energy hadron phenomenology as the master equation for the treatment of mesons and baryons as bound states of light and heavy constituent quarks (see e.g. Refs. [18, 19]). By constructing a phenomenological Lagrangian including the couplings of the bound state to its constituents and the constituents to other final state particles we evaluated meson-loop diagrams which describe the different decay modes of the molecular states (see details in [15, 16]).

In the present paper we proceed as follows. In Sec. II we first discuss the basic notions of our approach. We discuss the effective Lagrangian for the treatment of the $\Lambda_c(2940)^+$ baryon as a superposition of the pD^{*0} and nD^{*+} molecular components. Moreover, we consider the two-body hadronic decays $\Lambda_c(2940)^+ \rightarrow pD^0, \Sigma_c^{++}\pi^-, \Sigma_c^0\pi^+$ in this section. In Sec. III we present our numerical results. Finally, in Sec. IV we present a short summary of our results.

II. APPROACH

In this section we discuss the formalism for the study of the $\Lambda_c(2940)^+$ baryon. First we adopt the convention that the spin and parity quantum numbers of the $\Lambda_c(2940)^+$ are $J^P = \frac{1}{2}^+$. But we also check the possibility of $J^P = \frac{1}{2}^-$

(it will be shown that the last possibility leads to an overestimate of the strong two-body decay widths and therefore must be excluded in our approach).

Following Ref. [3] we consider this state as a superposition of the molecular pD^{*0} and nD^{*+} components with the adjustable mixing parameter or mixing angle θ :

$$|\Lambda_c(2940)^+\rangle = \cos\theta |pD^{*0}\rangle + \sin\theta |nD^{*+}\rangle. \quad (1)$$

The values $\sin\theta = 1/\sqrt{2}$, $\sin\theta = 0$ or $\sin\theta = 1$ correspond to the cases of ideal mixing, of a vanishing nD^{*+} or pD^{*0} component, respectively. Our approach is based on an effective interaction Lagrangian describing the coupling of the $\Lambda_c(2940)^+$ to its constituents. We propose a setup for the $\Lambda_c(2940)^+$ in analogy to mesons consisting of a heavy quark and light antiquark, i.e. the heavy D^* meson defines the center of mass of the $\Lambda_c(2940)^+$, while the light nucleon surrounds the D^* . The distribution of the nucleon relative to the D^* meson we describe by the correlation function $\Phi(y^2)$ depending on the Jacobi coordinate y . The simplest form of such a Lagrangian reads

$$\mathcal{L}_{\Lambda_c}(x) = g_{\Lambda_c} \bar{\Lambda}_c^+(x) \Gamma^\mu \int d^4y \Phi(y^2) \left(\cos\theta D_\mu^{*0}(x) p(x+y) + \sin\theta D_\mu^{*+}(x) n(x+y) \right) + \text{H.c.}, \quad (2)$$

where g_{Λ_c} is the coupling constant of the $\Lambda_c(2940)^+$ to the constituents and Γ^μ is the corresponding Dirac matrix related to the spin-parity of the $\Lambda_c(2940)^+$. In particular we have $\Gamma^\mu = \gamma^\mu$ for $J^P = \frac{1}{2}^+$ and $\Gamma^\mu = \gamma^\mu \gamma^5$ for $J^P = \frac{1}{2}^-$. A basic requirement for the choice of an explicit form of the correlation function $\Phi(y^2)$ is that its Fourier transform vanishes sufficiently fast in the ultraviolet region of Euclidean space to render the Feynman diagrams ultraviolet finite. We adopt a Gaussian form for the correlation function. The Fourier transform of this vertex is given by

$$\tilde{\Phi}(p_E^2/\Lambda^2) \doteq \exp(-p_E^2/\Lambda^2), \quad (3)$$

where p_E is the Euclidean Jacobi momentum. Here, $\Lambda \sim m_N \sim 1$ GeV is a size parameter characterizing the distribution of the nucleon in the $\Lambda_c(2940)^+$ baryon, which is of order of the nucleon mass or 1 GeV. The size parameter Λ is a free parameter in our approach.

The coupling constant g_{Λ_c} is determined by the compositeness condition [15, 17–19]. It implies that the renormalization constant of the hadron wave function is set equal to zero with:

$$Z_{\Lambda_c} = 1 - \Sigma'_{\Lambda_c}(m_{\Lambda_c}) = 0. \quad (4)$$

Here, $\Sigma'_{\Lambda_c}(m_{\Lambda_c})$ is the derivative of the $\Lambda_c(2940)^+$ mass operator shown in Fig.1. In order to evaluate the coupling g_{Λ_c} we use the standard free propagators for the intermediate particles:

$$iS_N(x-y) = \langle 0|TN(x)\bar{N}(y)|0\rangle = \int \frac{d^4k}{(2\pi)^4 i} e^{-ik(x-y)} S_N(k), \quad S_N(k) = \frac{1}{m_N - \not{k} - i\epsilon} \quad (5)$$

for the nucleons and

$$iS_{D^*}^{\mu\nu}(x-y) = \langle 0|TD^{*\mu}(x)D^{*\nu\dagger}(y)|0\rangle = \int \frac{d^4k}{(2\pi)^4 i} e^{-ik(x-y)} S_{D^*}^{\mu\nu}(k), \quad S_{D^*}^{\mu\nu}(k) = \frac{-g^{\mu\nu} + k^\mu k^\nu/m_{D^*}^2}{m_{D^*}^2 - k^2 - i\epsilon} \quad (6)$$

for the D^* vector mesons.

In order to study the strong two-body decays $\Lambda_c(2940)^+ \rightarrow pD^0$ and $\Lambda_c(2940)^+ \rightarrow \Sigma_c^{++0}\pi^{-,+}$ (see Fig.2) we need to know the coupling of the $\Lambda_c(2940)^+$ constituents to the final state particles. In particular, we need the Lagrangian describing the coupling of ND^* pairs to pD^0 and $\Sigma_c\pi$. Such effective Lagrangians containing the coupling of two baryon fields with $J^P = \frac{1}{2}^+$, one vector and one pseudoscalar field have in general the form:

$$\mathcal{L}_{VPBB} \sim \bar{B}i\gamma^\mu\gamma^5 BV_\mu P + \text{H.c.} \quad (7)$$

The derivation of such a flavor SU(4) invariant Lagrangian is discussed in Appendix A. Here we just display the terms relevant for our calculations:

$$\begin{aligned} \mathcal{L}_{VPBB}(x) = & -\frac{G}{F_D} \bar{p}(x) i\gamma^\mu \gamma^5 \left(\frac{2}{5} p(x) D_\mu^{*0}(x) + \frac{1}{2} n(x) D_\mu^{*+}(x) \right) \bar{D}^0(x) \\ & + \frac{G}{F_\pi} \bar{\Sigma}_c^{++}(x) i\gamma^\mu \gamma^5 \left(\frac{9}{10} p(x) D_\mu^{*0}(x) + n(x) D_\mu^{*+}(x) \right) \pi^+(x) \\ & + \frac{G}{F_\pi} \bar{\Sigma}_c^0(x) i\gamma^\mu \gamma^5 \left(p(x) D_\mu^{*0}(x) + \frac{9}{10} n(x) D_\mu^{*+}(x) \right) \pi^-(x) + \text{H.c.} \end{aligned} \quad (8)$$

where $G = g_{\rho\pi\pi}g_A$ is the coupling constant; $g_{\rho\pi\pi} = 6$ is the $\rho\pi\pi$ coupling and $g_A = 1.2695$ is the nucleon axial charge; $F_\pi = f_\pi/\sqrt{2} = 92.4$ MeV and $F_D = f_D/\sqrt{2} = 145.5$ MeV are the leptonic decay constants of π and D mesons, respectively.

The strong two-body decay widths of the $\Lambda_c(2940)^+$ baryon are calculated according to the expressions:

$$\Gamma(\Lambda_c[1/2^+] \rightarrow B + M) = \frac{g_{\Lambda_c BM}^2}{16\pi m_{\Lambda_c}^3} \lambda^{1/2}(m_{\Lambda_c}^2, m_B^2, m_M^2) \left((m_{\Lambda_c} - m_B)^2 - m_M^2 \right) \quad (9)$$

for the positive parity $\Lambda_c(2940)^+$ state and accordingly

$$\Gamma(\Lambda_c[1/2^-] \rightarrow B + M) = \frac{f_{\Lambda_c BM}^2}{16\pi m_{\Lambda_c}^3} \lambda^{1/2}(m_{\Lambda_c}^2, m_B^2, m_M^2) \left((m_{\Lambda_c} + m_B)^2 - m_M^2 \right) \quad (10)$$

for the negative parity choice for $\Lambda_c(2940)^+$. The letters B and M denote the final baryon and pseudoscalar meson; $\lambda(x, y, z) = x^2 + y^2 + z^2 - 2xy - 2yz - 2xz$ is the Källén function; m_{Λ_c} , m_B and m_M are the masses of the $\Lambda_c(2940)^+$, the final baryon B and the meson M . In above expressions $g_{\Lambda_c BM}$ and $f_{\Lambda_c BM}$ are the effective coupling constants defining the interaction of the $\Lambda_c(2940)^+$ having quantum numbers $J^P = \frac{1}{2}^+$ or $\frac{1}{2}^-$ with the (BM) pair:

$$\begin{aligned} \mathcal{L}_{\Lambda_c BM}^{1/2^+}(x) &= g_{\Lambda_c BM} \bar{\Lambda}_c(x) i\gamma_5 B(x) M(x) + \text{H.c.} \\ \mathcal{L}_{\Lambda_c BM}^{1/2^-}(x) &= f_{\Lambda_c BM} \bar{\Lambda}_c(x) B(x) M(x) + \text{H.c.} \end{aligned} \quad (11)$$

III. NUMERICAL RESULTS

In Table 1 we present the numerical results for the partial two-body decay widths of the $\Lambda_c(2940)^+$ at $\Lambda = 1$ GeV – the dimensional parameter describing the distribution of the nucleon around the D^* which is located in the center-of-mass of the $\Lambda_c(2940)^+$. Note that the results are sensitive to the choice of the cutoff parameter Λ . An increase of Λ leads to large values for the $\Lambda_c(2940)^+$ decay widths. We also vary $\cos\theta$ – the mixing parameter of the pD^{*0} and nD^{*+} components from 0 to 1. For the case $J^P = \frac{1}{2}^+$ the sum of the partial decay widths is of the order of 1 MeV, at least consistent with current upper values set by the observed total width. For the alternative case of $J^P = \frac{1}{2}^-$ the dominant partial decay width is about 1 GeV in complete contradiction with the experimental constraints. This dramatic increase in magnitude of the partial decay widths for $J^P = \frac{1}{2}^-$ is mainly explained by the large phase space integral [see Eqs. (9) and (10)]. We therefore conclude that in the context of a molecular interpretation spin-parity $J^P = \frac{1}{2}^+$ of the $\Lambda_c(2940)^+$ state is clearly favored. The hadron molecule scenario with $J^P = \frac{1}{2}^+$ results in partial decay widths for the modes $\Sigma_c^{++}\pi^-$ and $\Sigma_c^0\pi^+$, which are dominant and about equal. The decay channel pD^0 is suppressed relative to $\Sigma_c^{++}\pi^-$ by a factor of about 4, details depending on the explicit value of the mixing angle. Also for transparency we present results for the effective couplings $g_{\Lambda_c BM}$ and $f_{\Lambda_c BM}$ of Eq. (11):

$$\begin{aligned} g_{\Lambda_c pD^0} &= -0.43 \pm 0.10, \quad g_{\Lambda_c \Sigma_c^{++}\pi^-} = 1.46 \pm 0.30, \quad g_{\Lambda_c \Sigma_c^0\pi^+} = 1.46 \pm 0.29, \\ f_{\Lambda_c pD^0} &= 1.26 \pm 0.34, \quad f_{\Lambda_c \Sigma_c^{++}\pi^-} = -4.25 \pm 0.97, \quad f_{\Lambda_c \Sigma_c^0\pi^+} = -4.42 \pm 0.78. \end{aligned} \quad (12)$$

IV. CONCLUSIONS

We pursue a hadronic molecule interpretation of the recently observed $\Lambda_c(2940)^+$ baryon studying its consequences for the strong two-body decay modes and the J^P quantum numbers. In the present scenario the $\Lambda_c(2940)^+$ baryon is supposed to be described by a superposition of $|pD^{*0}\rangle$ and $|nD^{*+}\rangle$ components with the explicit admixture expressed by the mixing angle θ . The possible decay channels pD^0 , $\Sigma_c^{++}\pi^-$ and $\Sigma_c^0\pi^+$ are fed by a ND^* meson loop which in turn arises from the hadronic constituents of the $\Lambda_c(2940)^+$. The choice $J^P = \frac{1}{2}^-$ is completely excluded by the present calculation resulting in partial decay widths of the order of 1 GeV. For $J^P = \frac{1}{2}^+$ we obtain the dominant decay channels $\Sigma_c^{++}\pi^-$ and $\Sigma_c^0\pi^+$ relative to the pD^0 mode. The absolute rates but less so the ratios of rates depend on the explicit molecule configuration expressed by θ . The sum of partial decay widths is consistent with the upper value set by the observed total width. An experimental determination of the partial decay widths for the modes pD and $\Sigma_c\pi$ could certainly help in clarifying the structure issue involving the $\Lambda_c(2940)^+$ baryon.

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Appendix A: Derivation of the phenomenological $VPBB$ interaction Lagrangian

First we consider the derivation of the phenomenological flavor SU(3) $VPBB$ interaction Lagrangian describing the coupling of vector (V) and pseudoscalar (P) mesons to two baryons ($\bar{B}B$). It can be generated by starting with the $\mathcal{O}(p)$ term of chiral perturbation theory (ChPT) describing the coupling of baryon fields (\bar{B}, B) with the chiral vielbein field u_μ :

$$\mathcal{L}_{PBB} = \frac{D}{2} \text{tr} \left(\bar{B} \gamma^\mu \gamma^5 \{u_\mu B\} \right) + \frac{F}{2} \text{tr} \left(\bar{B} \gamma^\mu \gamma^5 [u_\mu B] \right). \quad (\text{A1})$$

D and F are the baryon axial coupling constants (we restrict to the SU(3) symmetric limit, where $D = 3F/2 = 3g_A/5$ with $g_A = 1.2695$ being the nucleon axial charge); the symbols tr , $\{\dots\}$ and $[\dots]$ denote the trace over flavor matrices, anticommutator and commutator, respectively. We use the standard notation for the basic blocks of the ChPT Lagrangian [20], where B is the octet of baryon fields, $U = u^2 = \exp(iP\sqrt{2}/F_P)$ is the chiral field collecting pseudoscalar fields P in the exponential parametrization with F_P being the octet leptonic decay constant, $u_\mu = iu^\dagger \nabla_\mu U u^\dagger$, ∇_μ denotes the covariant derivative acting on the chiral field including external vector (v_μ) and axial (a_μ) sources: $\nabla_\mu U = \partial_\mu U - i(v_\mu + a_\mu)U + iU(v_\mu - a_\mu)$.

The vector sources can be identified with the vector mesons V_μ if the latter are considered as gauge particles and introduced via the minimal substitution (for more details see e.g. [21]). The SU(3) baryon (B), pseudoscalar meson (P) and vector meson (V) matrices read as:

$$B = \begin{pmatrix} \Sigma^0/\sqrt{2} + \Lambda/\sqrt{6} & \Sigma^+ & p \\ \Sigma^- & -\Sigma^0/\sqrt{2} + \Lambda/\sqrt{6} & n \\ \Xi^- & \Xi^0 & -2\Lambda/\sqrt{6} \end{pmatrix}, \quad (\text{A2})$$

$$P = \begin{pmatrix} \pi^0/\sqrt{2} + \eta/\sqrt{6} & \pi^+ & K^+ \\ \pi^- & -\pi^0/\sqrt{2} + \eta/\sqrt{6} & K^0 \\ K^- & \bar{K}^0 & -2\eta/\sqrt{6} \end{pmatrix}, \quad (\text{A3})$$

$$V = \begin{pmatrix} \rho^0/\sqrt{2} + \omega/\sqrt{2} & \rho^+ & K^{*+} \\ \rho^- & -\rho^0/\sqrt{2} + \omega/\sqrt{2} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & -\phi \end{pmatrix}. \quad (\text{A4})$$

The required SU(3) $VPBB$ interaction Lagrangian reads:

$$\mathcal{L}_{VPBB} = g_V \frac{D+F}{F_P} \text{tr} \left(\bar{B} i \gamma^\mu \gamma^5 [V_\mu P] B \right) + g_V \frac{D-F}{F_P} \text{tr} \left(\bar{B} i \gamma^\mu \gamma^5 B [V_\mu P] \right), \quad (\text{A5})$$

where $g_V = g_{\rho\pi\pi} = 6$ is the strong $\rho\pi\pi$ coupling constant. The extended SU(4) $VPBB$ interaction Lagrangian has the more complicated form

$$\begin{aligned} \mathcal{L}_{VPBB} = & i g_1 \bar{B}^{kmn} \gamma^\mu \gamma^5 [V_\mu, P]_k^l B_{lmn} + i g_2 \bar{B}^{kmn} \gamma^\mu \gamma^5 [V_\mu, P]_k^l B_{lnm} \\ & + i g_3 \bar{B}^{kmn} \gamma^\mu \gamma^5 ((V_\mu)_k^l P_m^s - P_k^l (V_\mu)_m^s) B_{lns} \\ & - i g_3 \bar{B}^{knm} \gamma^\mu \gamma^5 ((V_\mu)_k^l P_m^s - P_k^l (V_\mu)_m^s) B_{lsn}, \end{aligned} \quad (\text{A6})$$

where B_{lmn} is a tensor with indices l, m, n running from 1 to 4 representing the 20-plet of baryons (see details in Refs. [22]); $(V_\mu)_k^l$ and P_k^l are the matrices representing the 15-plets of vector and pseudoscalar fields. The baryon tensor satisfies the conditions

$$B_{lmn} + B_{mnl} + B_{nlm} = 0, \quad B_{lmn} = B_{mln}. \quad (\text{A7})$$

The full list of physical states in terms of SU(4) tensors is given in Ref. [22]. Here we only display a few of them:

$$\begin{aligned} p &= B_{112} = -2B_{121} = -2B_{211}, \quad n = -B_{221} = 2B_{212} = 2B_{122}, \\ \Sigma_c^{++} &= B_{114} = -2B_{141} = -2B_{411}, \quad \Sigma_c^0 = -B_{224} = 2B_{242} = 2B_{422}, \\ \pi^+ &= P_1^2, \quad \pi^- = P_2^1, \quad D^0 = P_4^1, \quad D^{*+} = V_4^2, \quad D^{*0} = V_4^1. \end{aligned} \quad (\text{A8})$$

The matching of the SU(3) and SU(4) $VPBB$ Lagrangians at tree level gives the following relations between the effective couplings:

$$\begin{aligned} g_{\rho\pi\pi} \frac{D}{F_P} &= \frac{3}{4}g_1 - \frac{3}{2}g_2, \\ g_{\rho\pi\pi} \frac{F}{F_P} &= \frac{5}{4}g_1 - g_2. \end{aligned} \quad (\text{A9})$$

Note that the coupling constant g_3 is left to be unmatched. Below we display the terms of the SU(4) $VPBB$ Lagrangian relevant for our calculations:

$$\begin{aligned} \mathcal{L}_{VPBB} &= \left(g_2 - \frac{5}{4}g_1\right) \bar{p} i \gamma^\mu \gamma^5 p D_\mu^{*0} \bar{D}^0 - \left(g_1 - \frac{5}{4}g_2\right) \bar{p} i \gamma^\mu \gamma^5 n D_\mu^{*+} \bar{D}^0 \\ &+ \left(\frac{g_1 + g_2}{4} - \frac{3}{2}g_3\right) \left(\bar{\Sigma}_c^{++} i \gamma^\mu \gamma^5 p D^{*0} \pi^+ + \bar{\Sigma}_c^0 i \gamma^\mu \gamma^5 n D^{*+} \pi^-\right) \\ &- \frac{3}{2}g_3 \left(\bar{\Sigma}_c^{++} i \gamma^\mu \gamma^5 n D^{*+} \pi^+ + \bar{\Sigma}_c^0 i \gamma^\mu \gamma^5 p D^{*0} \pi^-\right) + \text{H.c.} \end{aligned} \quad (\text{A10})$$

We can estimate the coupling g_3 using the following procedure: the corresponding vertices are generated by static one-nucleon exchange between the pairs of (nucleon, π) and (D^* , Σ_c) [see Fig.3]. We therefore can express the couplings of $\bar{\Sigma}_c^{++} n D^{*+} \pi^+$ and $\bar{\Sigma}_c^0 p D^{*0} \pi^-$ (which are proportional to the coupling g_3) in terms of the πNN and $D^* N \Sigma_c$ couplings as

$$-\frac{3}{2}g_3 = \frac{g_{D^* N \Sigma_c} g_{\pi NN}}{m_N} \sqrt{2}. \quad (\text{A11})$$

Here the coupling $g_{D^* N \Sigma_c}$ can be fixed by the matching of SU(3) and SU(4) VBB Lagrangians. In particular, the SU(4) VBB Lagrangian has the form (here and in the following we neglect the tensorial part of the VBB interaction containing a derivative acting on the vector field)

$$\mathcal{L}_{VBB} = f_1 \bar{B}^{kmn} \gamma^\mu (V_\mu)_k^l B_{lmn} + f_2 \bar{B}^{kmn} \gamma^\mu (V_\mu)_k^l B_{lnm} \quad (\text{A12})$$

where the f_1 and f_2 are the coupling constants. We do not include the term $f_3 \bar{B}^{kmn} \gamma^\mu B_{kmn} \text{tr}(V_\mu)$ because we suppose that the ϕNN coupling vanishes due to the Okuba-Zweig-Iizuka (OZI) rule. In Ref. [23] it was shown that an estimate of the ϕNN coupling from a dispersive analysis results in the value $g_{\phi NN} = -0.24$. Using the definitions of the ρNN and ωNN couplings with

$$\begin{aligned} \mathcal{L}_{\rho NN} &= \frac{g_{\rho NN}}{2} \bar{N} \gamma^\mu \vec{\rho}_\mu \vec{\tau} N \\ \mathcal{L}_{\omega NN} &= \frac{g_{\omega NN}}{2} \bar{N} \gamma^\mu \omega_\mu N \end{aligned} \quad (\text{A13})$$

we can express the SU(4) couplings in terms of the $g_{\rho NN}$ and $g_{\omega NN}$ coupling constants as:

$$\begin{aligned} f_1 &= \frac{2}{3\sqrt{2}} \left(\frac{5}{3} g_{\omega NN} - g_{\rho NN} \right), \\ f_2 &= \frac{4}{3\sqrt{2}} \left(\frac{2}{3} g_{\omega NN} - g_{\rho NN} \right). \end{aligned} \quad (\text{A14})$$

Taking the SU(3) predictions for the $g_{\rho NN}$ and $g_{\omega NN}$ couplings of

$$g_{\rho NN} = 6, \quad g_{\omega NN} = 3g_{\rho NN} \quad (\text{A15})$$

we get

$$f_1 = \frac{8}{3\sqrt{2}}g_{\rho NN} \simeq 11.32, \quad f_2 = \frac{4}{3\sqrt{2}}g_{\rho NN} \simeq 5.66, \quad g_{D^*N\Sigma_c} = \frac{1}{4}(f_1 + f_2) = \frac{1}{\sqrt{2}}g_{\rho NN} \simeq 4.24. \quad (\text{A16})$$

Finally we get for the SU(4) coupling g_3 the expression

$$g_3 = -\frac{2}{3F_P}g_{\rho\pi\pi}g_A \quad (\text{A17})$$

where we use the universality of the ρ meson with $g_{\rho\pi\pi} = g_{\rho NN}$. In the evaluation we use different values for the leptonic decay constants F_π , F_D , etc. associated with π , D , etc. in order to take into account flavor symmetry breaking corrections.

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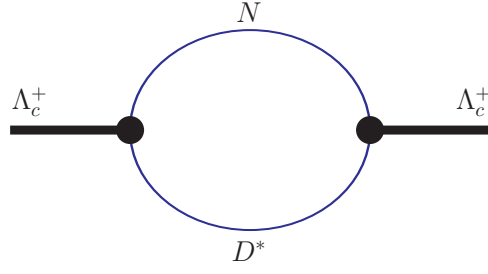


FIG. 1: Diagram describing the $\Lambda_c(2940)^+$ mass operator.

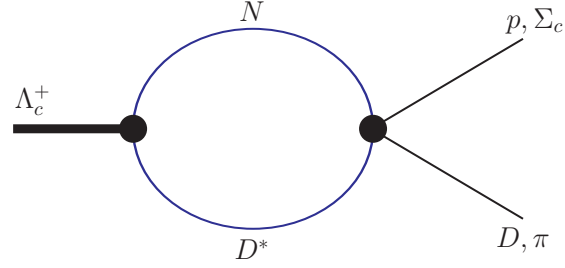


FIG. 2: Diagrams contributing to the decays $\Lambda_c(2940)^+ \rightarrow p D^0, \Sigma_c^{++} \pi^-, \Sigma_c^0 \pi^+$.

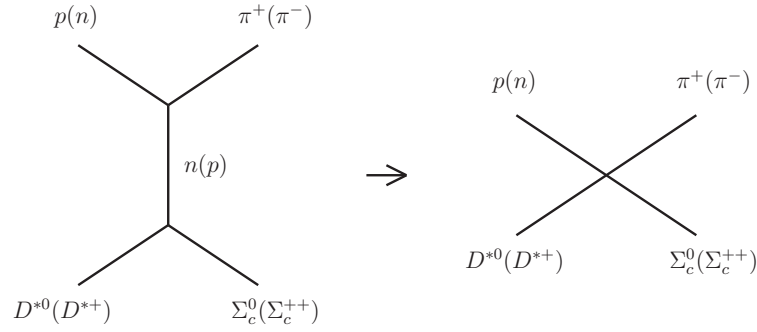


FIG. 3: Estimate for the coupling g_3 .

Table 1. Partial decay widths of $\Lambda_c(2940)^+$ in MeV.

$\cos \theta$	$\frac{1}{2}^+$ modes			$\frac{1}{2}^-$ modes		
	$\Lambda_c^+ \rightarrow pD^0$	$\Lambda_c^+ \rightarrow \Sigma_c^{++}\pi^-$	$\Lambda_c^+ \rightarrow \Sigma_c^0\pi^+$	$\Lambda_c^+ \rightarrow pD^0$	$\Lambda_c^+ \rightarrow \Sigma_c^{++}\pi^-$	$\Lambda_c^+ \rightarrow \Sigma_c^0\pi^+$
1	0.11	0.58	0.72	19.15	612.68	756.72
0.95	0.17	0.85	0.98	29.75	907.64	1040.36
0.9	0.20	0.96	1.08	34.40	1033.00	1153.95
0.8	0.23	1.11	1.20	41.09	1208.89	1305.10
0.7	0.25	1.20	1.27	46.17	1338.06	1407.80
0.6	0.27	1.27	1.30	50.24	1437.58	1478.96
0.5	0.28	1.31	1.32	53.47	1511.85	1522.78
0.4	0.29	1.32	1.30	55.83	1560.10	1538.24
0.3	0.29	1.32	1.30	55.83	1560.10	1538.24
0.2	0.29	1.30	1.26	57.15	1577.04	1519.78
0.1	0.26	1.14	1.03	54.20	1447.05	1309.75
0.05	0.24	1.04	0.91	50.68	1334.05	1174.51
0	0.18	0.74	0.60	38.15	964.41	781.52